# Winter performance of certified passive houses In a Temperate Maritime Climate – nZEB Compliant?

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## Introduction

Near Zero Energy Buildings (nZEB) are mandated across Europe for all dwellings built after 2020. As efforts increase to reduce winter heating demand and build low-energy and nZEB dwellings e.g. using the well-established passive house (PH) standard[i] , UK post occupancy analysis of low-energy dwellings (e.g. [ii]) has focused on dwellings in mainland UK, with publications on Northern Ireland PH dwellings primarily focusing on social housing (e.g. [iii] and [iv]). This paper presents recorded energy and Indoor Environmental Quality (I.E.Q) performance of owner occupied certified passive houses (PH) and contemporaneously constructed dwellings which comply with the minimum building regulations in the temperate maritime climate of Northern Ireland over the winter period. The potential of the PH in meeting nZEB is considered given that the cost of building to the nZEB standard has been shown to be comparable to meeting national building regulations[v].

## Method

This paper presents an assessment of the monitored winter performance of four certified newbuild Passive Houses (PH)[vi] and compares it to five houses built to comply with the minimum building regulations standard (B Regs), located in Northern Ireland (NI). Given the similarities in the cost of nZEB and PH standards[vii], it is likely that the PH standard will be used to comply with nZEB requirement and therefore affords an opportunity to compare the recorded performance of the potential future nZEB building stock with that which is currently being constructed. The energy performance certificates (EPCs) of the constructed PH's are also used to determine if they are nZEB compliant. The paper represents a subset of the dwellings being monitored over a full year as part of a study of energy consumption and Indoor Environmental Quality (IEQ) of 23 houses on the island of Ireland (see fig 1).

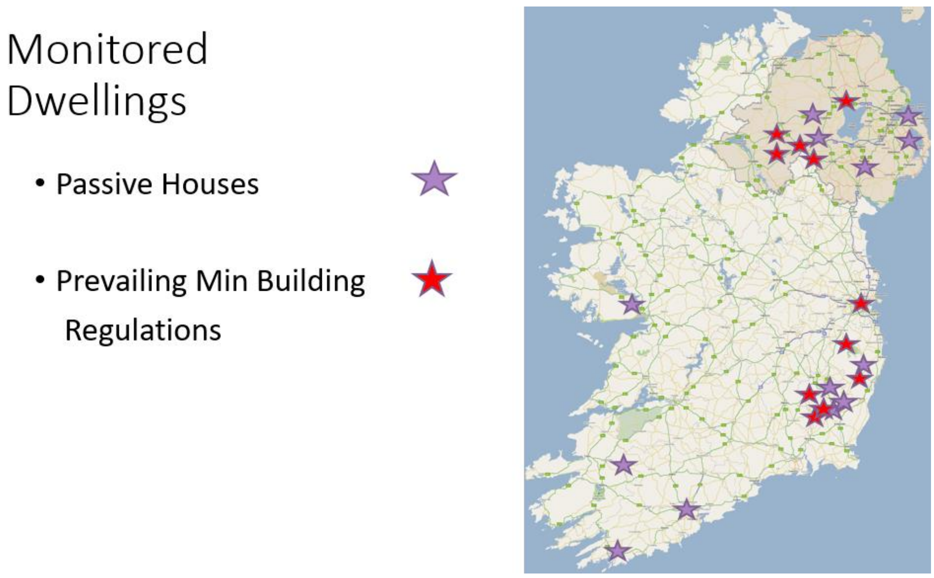



**Figure 1 Locations of monitored passive houses and Building Regulations Houses**

In common with the methodology employed in recent metadata studies[ix], data is presented for the living rooms and master bedrooms. Data covers the period November and December 2016 and January 2017 for the NI dwellings (see table 1) and supplements an analysis which has been carried out over the 2016 summer period[viii] .
The metrics being gathered at five-minute intervals for the nine houses include: occupancy profile; indoor air temperature; indoor relative humidity; indoor carbon dioxide concentrations; outdoor temperature; outdoor relative humidity; barometric pressure and energy consumption.

| House | Building Type | Construction | Constructed | Size {$m^2$} |
|---|---|---|---|---|
| PH 1 | 2 storey Hse, Detached | TF | 2014 | 158 |
| PH 2 | Bungalow, Detached | TF | 2013 | 220 |
| PH 3 | Bungalow, Detached | TF | 2011 | 145 |
| PH 4 | Detached | TF | 2016 | 247 |
| PH 5 | Under construction | n/a | 2017 | n/a |
| | | | | |
| BRegs 1 | 2 storey Hse, Detached | Block | 2010 | 329 |
| BRegs 2 | 2 story hose, Detached | TF | 2014 | 294 |
| BRegs 3 | 2 Storey, Detached | Block | 2013 | 230 |
| BRegs 4 | 2 Storey, Detached | block | 2016 | 210 |
| BRegs 5 | 2 storey Hse, Detached | Block | 2015 | 246 |

**Table 1 Overview of the Monitored Houses**

Bands have been established for the key metrics being monitored and the percentage of time individual metrics exceed the thresholds are presented to assist the reader obtain insights. Passive Houses are designed to have a uniform set temperature of 20°C throughout. A temperature threshold has therefore been set at 20°C. Thresholds have been defined to reflect the set temperatures in SAP at 21°C for the living room and 18°C for the other parts of the dwelling. A set temperature of 24°C is required in SAP in the case of air-conditioned buildings, and the final threshold temperature of 25°C reflects the temperature that passive houses are allowed to exceed for no more than 10% of the time.

## Results - Overview

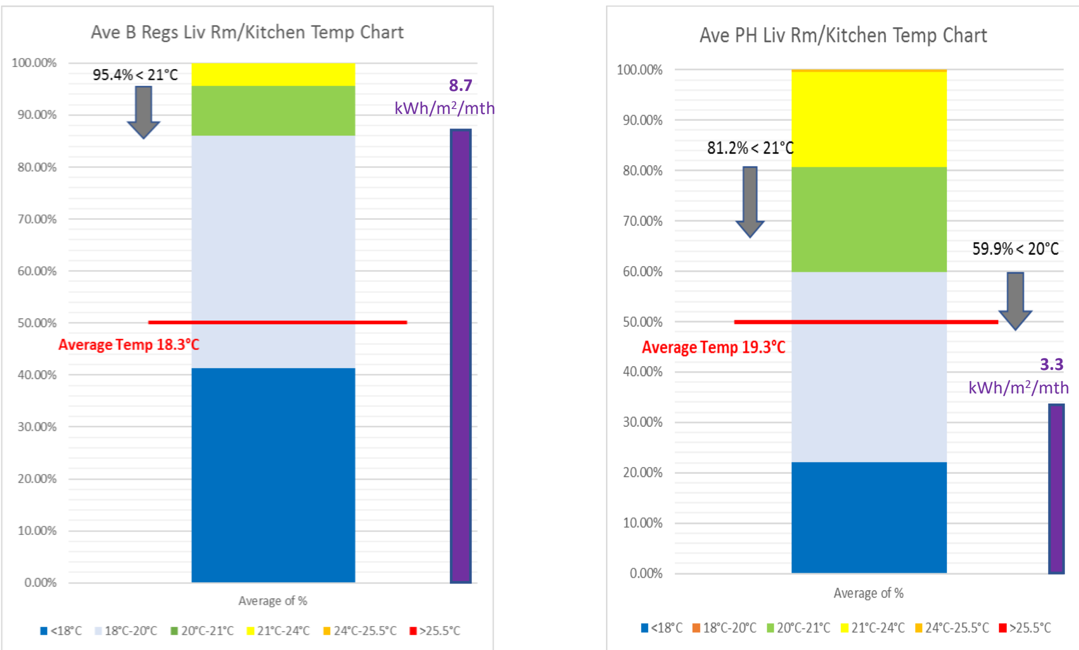



**Figure 2 Comparison of Living Room Temperatures and Building Heating Energy Consumption**

Overall, it was found that the passive houses required only 38% of the heating energy per $m^2$ per month whilst at the same time experiencing a 1°C higher average temperature than the houses built to the minimum building regulations (Figure 2). The average temperature of the bedrooms are similar, with the Passive House bedrooms being on average 0.2°C cooler than houses built to the minimum building regulations.

The passive houses were also seen to exhibit lower and more uniform average concentrations of carbon dioxide (612 ppm for the living rooms and 690 ppm for the bedrooms) compared with the houses complying with the minimum building regulations (677 ppm in the living rooms and 824 ppm in the bedroom). Initial investigations indicate that the mechanical heat recovery and ventilation systems employed in the passive houses may be contributing to the improved indoor air quality.

### *Results – Temperature profiles*

Figures 3, 4, 5 and 6 give the proportion of time that temperatures were experienced in the building regulations and passive houses both individually and as groups over the period broken down into the distinct temperature bands previously defined in addition to the average temperatures.

Figures 3 and 4 refer to the living room temperatures. The average temperature in the group of building regulations houses is seen to be 18.3°C compared with 19.3°C for the group of passive houses. Considering the set temperature for passive houses (20°C), the Passive House living rooms on average are seen to meet or exceed this threshold for 40.1 % of the time, while the building regulations houses meet or exceed 20°C for only 13.9 % of the time, and fall below the assumed building regulations set temperature of 21°C for 95.4% of the time.

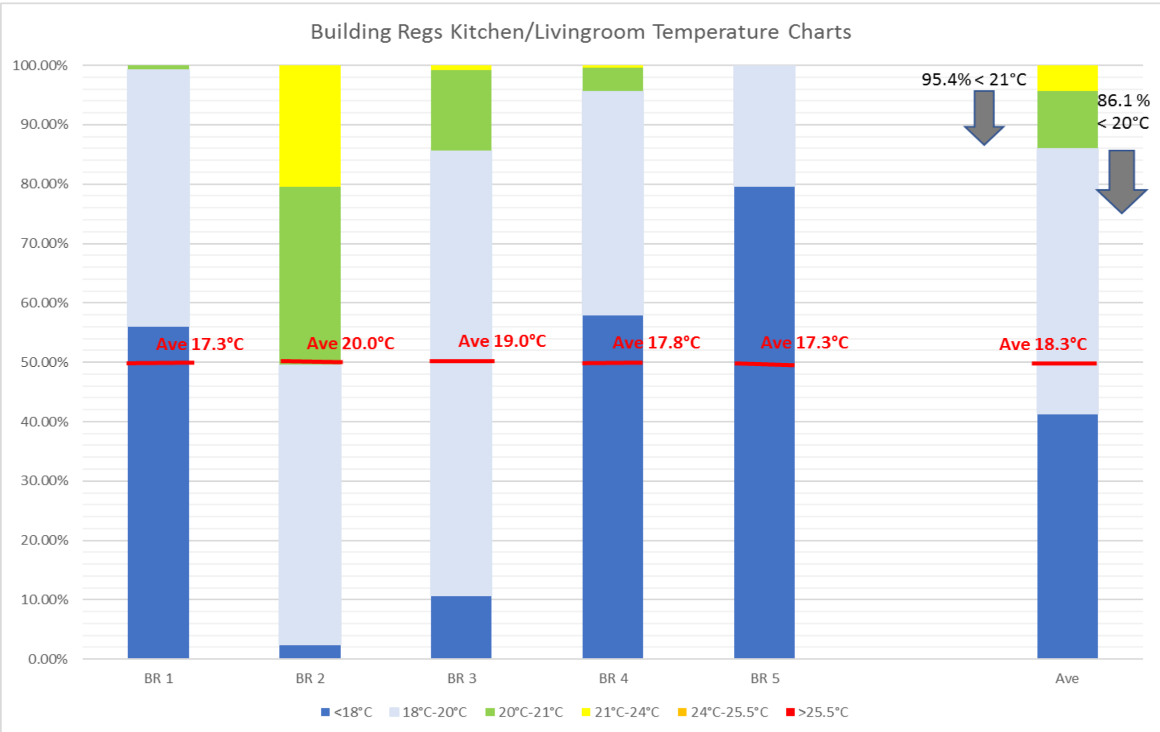



**Figure 3 Average building regulations living room temps Nov & Dec 2016, Jan 2017**

Considering the individual houses, PH 2 is seen to exhibit the lowest temperatures of all houses, with an average temperature of 16.5°C. This reflects the fact that the house is unoccupied (and unheated) for large periods of time. In the same manner, B Regs 5 is seen to be an outlier - the house records the coolest living room and the warmest bedroom of all the building regulations houses monitored. It was found that the monitoring equipment had been moved from the standard positions, thereby significantly affecting the recorded temperatures.

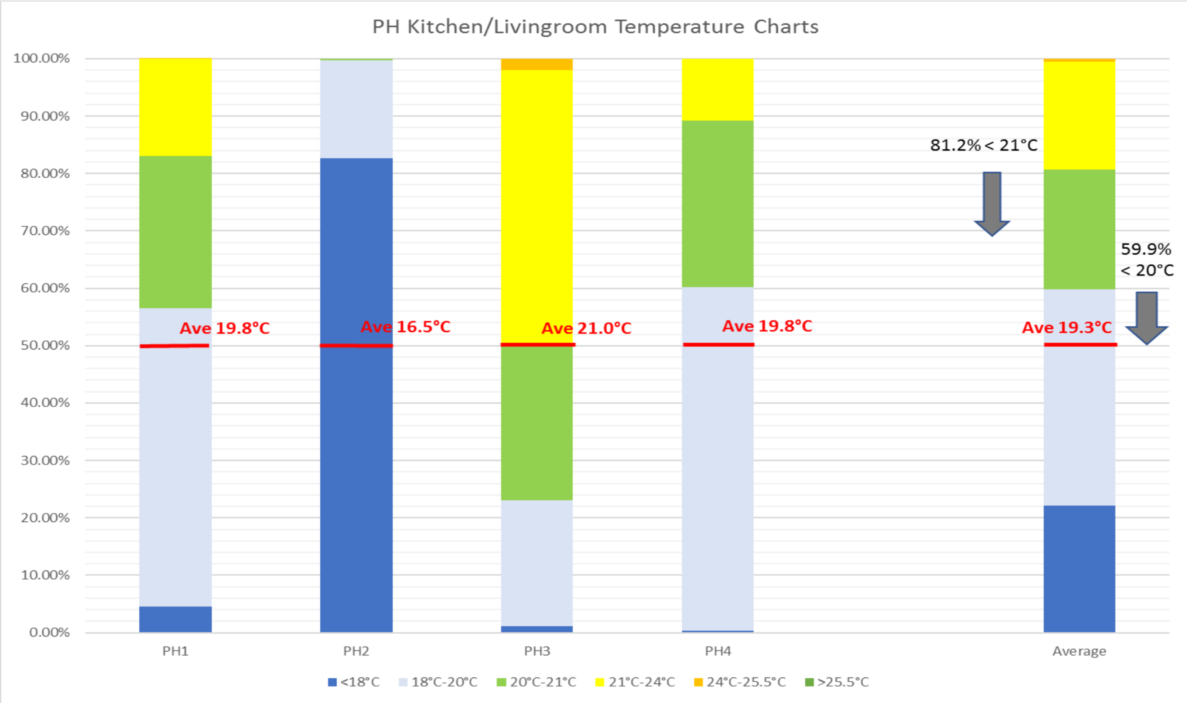



**Figure 4 Chart of the NI Passive House living room temps, Nov & Dec 2016, Jan 2017**

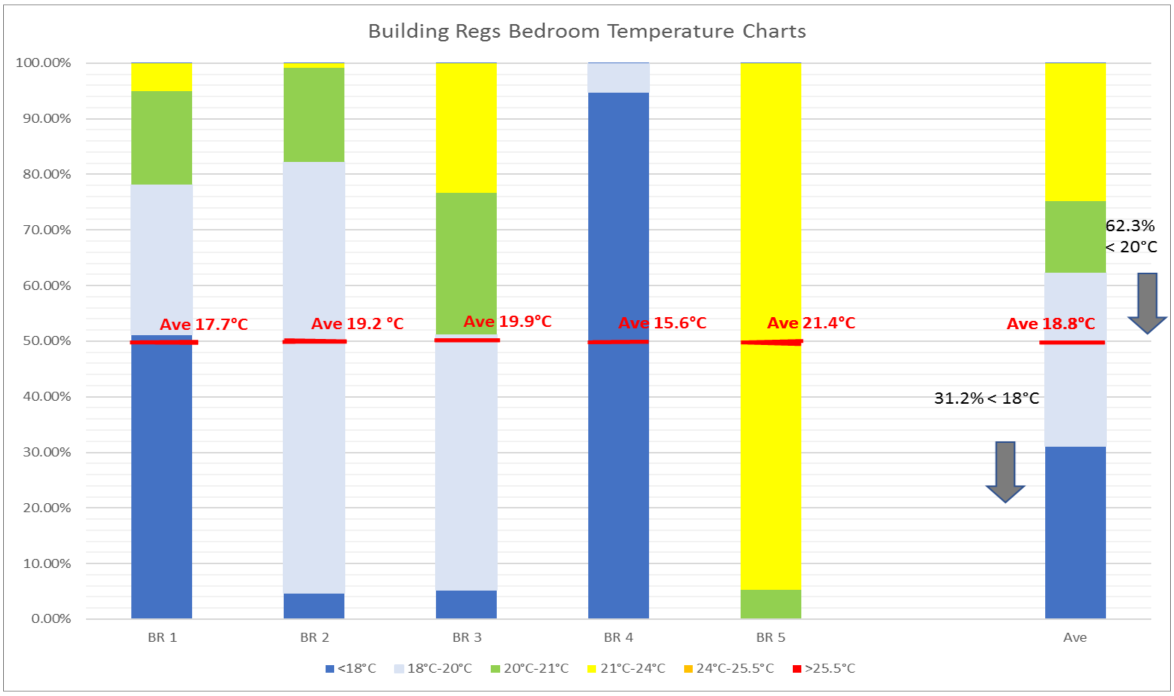



**Figure 5 Chart giving the building regulations bedroom temps Nov & Dec 2016, Jan 2017**

Considering figures 5 and 6, it is seen that the trend of higher average temperatures in the passive houses does not continue in the monitored bedrooms, with the average temperature being on average 0.2°C lower in the passive houses (18.6°C compared with 18.8°C respectively). During the winter period the temperatures are below the building regulations assumed set temperature of 18°C for 45% of the time (passive houses) and 31.2% of the time (B Regs). Considering the set temperature of 20°C of the Passive House standard, the temperature is below the threshold for 70% of the time in the passive houses and 62 % time in houses complying with the minimum building regulations.

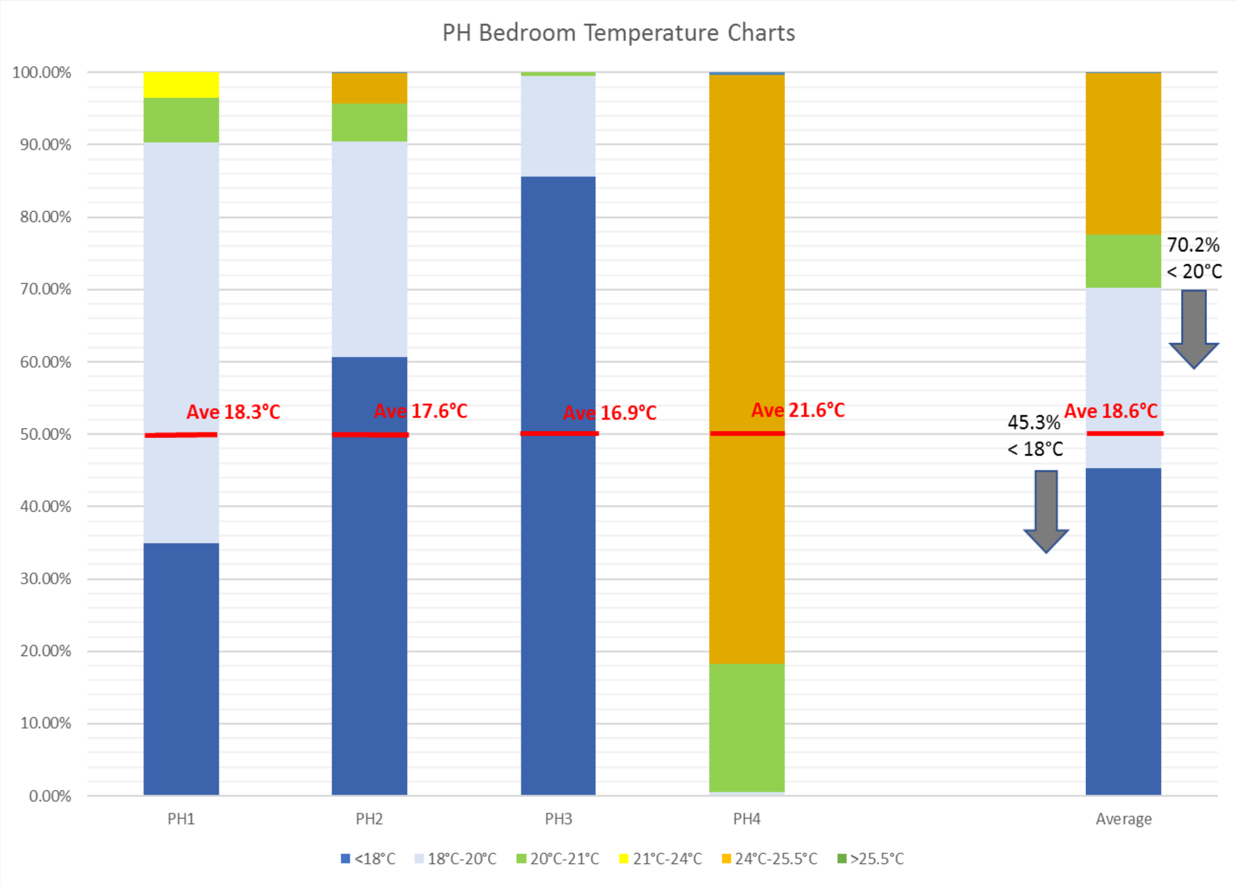



**Figure 6 Chart giving the Passive House bedroom temperatures for Nov & Dec 2016, Jan 2017**

## Results - Review of Key IEQ Parameters

Figure 7 shows the key parameter averages for the monitored living rooms and bedrooms of the passive houses and houses complying with the minimum building regulations. It is seen that the average carbon dioxide concentrations appear lower and more uniform in the passive houses compared with the houses complying with the minimum building regulations. While this could be due to the forced ventilation system of passive houses, further investigation is needed, as there appears to be an error in CO2 readings in the B Regs 2 for two months, and readings are high for B Regs 3, despite the presence of a positive input ventilation system and more widespread monitoring is required to validate the findings. The possibility of high CO2 readings due to insufficient ventilation in non PH does need further investigation.

It is noted that the relative humidity recorded in the living rooms is approximately 4 - 8% higher than that recorded in the bedrooms of both the passive houses and building regulations houses. This may be a characteristic of the monitoring equipment, as during calibration, the units located in the living rooms have been found to read higher relative humidities than the module type used in the bedroom. Despite this potential instrumental error which may be influencing the results, it does appear that the relative humidities in the building regs houses exceed those recorded in the passive houses in both the living rooms and bedrooms.

Building Regulations Houses

| Kit/Liv Rm | Temp | RH | CO2 |
|---|---|---|---|
| Ave | {°C} | {%} | {ppm} |
| B Regs 1 | 17.3 | 60.7 | 581.6 |
| B Regs 2 | 20.0 | 60.5 | 437.8 |
| B Regs 3 | 19.0 | 63.4 | 960.1 |
| B Regs 4 | 17.8 | 63.4 | 701.3 |
| B Regs 5 | 17.3 | 68.8 | 706.2 |
| | | | |
| Average | 18.3 | 63.3 | 677.4 |

| Bedroom | Temp | RH | CO2 |
|---|---|---|---|
| Ave | {°C} | {%} | {ppm} |
| B Regs 1 | 17.7 | 50.6 | 536.2 |
| B Regs 2 | 19.3 | 55.7 | 927.6 |
| B Regs 3 | 20.0 | 56.5 | 1242.5 |
| B Regs 4 | 15.6 | 60.4 | 621.2 |
| B Regs 5 | 21.4 | 50.8 | 792.7 |
| | | | |
| Average | 18.8 | 54.8 | 824.0 |

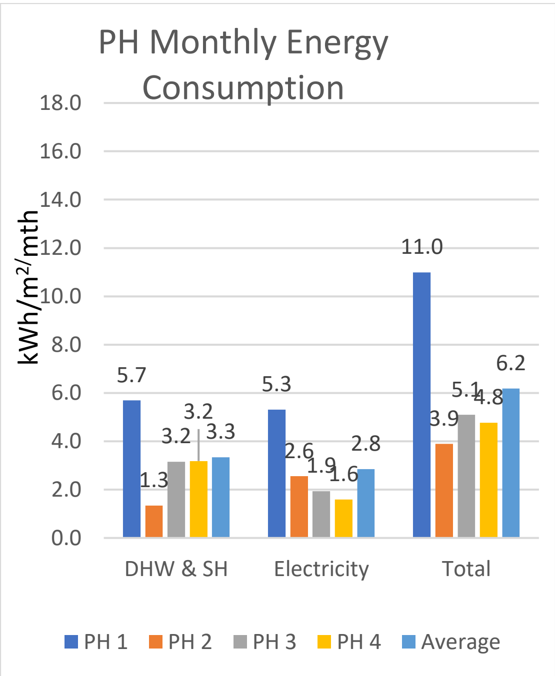
Passive Houses

| Kit/Liv Rm | Temp | RH | CO2 |
|---|---|---|---|
| Ave | {°C} | {%} | {ppm} |
| PH 1 | 19.8 | 54.5 | 627.0 |
| PH 2 | 16.5 | 55.6 | 455.9 |
| PH 3 | 21.0 | 47.1 | 646.1 |
| PH 4 | 19.8 | 55.4 | 722.1 |
| | | | |
| Average | 19.3 | 53.1 | 612.8 |

| Bedroom | Temp | RH | CO2 |
|---|---|---|---|
| Ave | {°C} | {%} | {ppm} |
| PH 1 | 18.4 | 50.7 | 721.2 |
| PH 2 | 17.6 | 48.0 | 596.8 |
| PH 3 | 16.9 | 50.9 | 493.7 |
| PH 4 | 21.6 | 48.2 | 946.9 |
| | | | |
| Average | 18.6 | 49.5 | 689.7 |

**Figure 7 Comparison of Passive Houses and Building Regulations Houses - Key Parameters averages**

**Results - Energy Consumption**



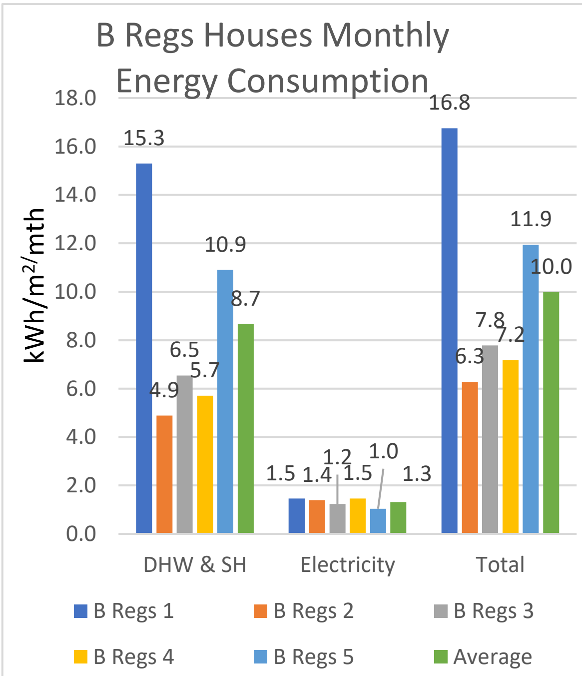




**Fig 8 Energy Consumption of PH and B Regs dwellings June 2016 to Jan 2017**

The details of the electrical energy consumption and space heating and DHW energy consumption for the passive houses and Building regulations houses for the months commencing 1st June 2016 to 1st February 2017 are given in figure 8.

***DHW and space heating energy consumption***

As can be seen from the first group of columns, the average energy consumption of the houses built to the minimum building regulations is 8.7 kWh/$m^2$/mth, almost 3 times that of the passive houses at 3.3 kWh/$m^2$/mth.
There is considerable spread in the energy consumption figures among the dwellings, with PH2 having the lowest energy consumption figure at 1.3 kWh/$m^2$/mth, PH 2 recorded a low occupancy level, and lower than average interior temperatures (living room temperature averaged 16.5°C compared with an overall average of 19.3°C for the group of passive houses). Equally PH 1 had a higher than average interior temperature, with the living room temperature recording 19.8°C on average.
Equally, looking at the DHW and space heating energy consumption figures for the building regulations houses, there is seen to be a significant spread, especially between B Regs 1 and B Regs 2, with a spread of three times the energy consumption per meter squared per month between the two dwellings. B Regs 1 is the oldest house in the sample, having been built in 2010. In addition, as can be seen from figure 4.5, the indoor air quality is very good, indicating a good ventilation rate, which may be impacting on the energy consumption figures.

***Electrical energy consumption***

The electrical energy consumption can be seen in the second groups of columns in figure 8 for the houses. On average the passive houses are seen to have an electrical energy consumption twice that of the building regulations houses (2.8 kWh/$m^2$/mth versus 1.3 kWh/$m^2$/mth). A portion of the difference is to be expected given that passive houses use a heat recovery and ventilation system which also provides electrical space heating to the dwelling. The high electrical energy consumption of PH 1 is due to the use of electricity for space heating, as it uses an electrical Aga.

***Discussion on Energy Consumption***

The total average monthly energy consumption of the minimum building regulations houses (10 kWh/$m^2$/mth), is almost twice that of the passive houses (at 6.2 kWh/$m^2$/mth). Almost 7 times the amount of energy is spent on heating building regulations houses compared with their electrical energy consumption (8.7 kWh/$m^2$/mth Vs 1.3 kWh/$m^2$/mth, as can be seen from figure 4.6). This compares markedly with the passive houses where space heating is only marginally above electrical energy consumption (3.3 kWh/$m^2$/mth Vs 2.8 kWh/$m^2$/mth). These figures highlight the significant impact that passive houses can have on the overall energy consumption of dwellings in Northern Ireland.

Whilst there is uncertainty caused by Brexit, the nZEB standard has been defined for the UK (and NI) in a recent report (zero carbon hub) as requiring primary energy for regulated laws of less than or equal to 43.6 kWh/$m^2$/a (or 44 kWh/$m^2$/a to the nearest integer). Of the four passive houses monitored, publicly available EPC's are available for three and indicate the "approximate Energy Use" unregulated loads are 40 kWh/$m^2$/a (PH 2), -39 kWh/$m^2$/a (PH 3) and 44 kWh/$m^2$/a (PH 4). While further more detailed analysis will be required once the nZEB standard for the UK is finalised, based on the primary energy use metric, the three passive houses are seen to comply with nZEB requirements.

## Conclusions

Monitoring has been carried out of four NI passive houses and five "standard" houses (built to the minimum building regulations) over the winter months 2016/17.

A key finding is the difference in terms of the interior temperatures with the group of Passive Houses recording on average a 1.0°C higher temperature in the living rooms despite requiring only 38% of the space heating energy consumption of the houses constructed to the minimum building regulations. The available EPCs of the monitored passive houses also indicate that the passive houses are currently nZEB compliant, in advance of the 2021 requirement.


**Acknowledgements**

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